

## Epitaxy

(redirected from *Epitaxially*)

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**Epitaxy** is a kind of interface between a thin film and a substrate. The term epitaxy (Greek; *epi* "above" and *taxis* "in ordered manner") describes an ordered crystalline growth on a monocrystalline substrate.

Epitaxial films may be grown from gaseous or liquid precursors. Because the substrate acts as a seed crystal, the deposited film takes on a lattice structure and orientation identical to those of the substrate. This is different from other thin-film deposition methods which deposit polycrystalline or amorphous films, even on single-crystal substrates. If a film is deposited on a substrate of the same composition, the process is called homoepitaxy; otherwise it is called heteroepitaxy.

**Homoepitaxy** is a kind of epitaxy performed with only one material. In homoepitaxy, a crystalline film is grown on a substrate or film of the same material. This technology is applied to growing a more purified film than the substrate and fabricating layers with different doping levels.

**Heteroepitaxy** is a kind of epitaxy performed with materials that are different from each other. In heteroepitaxy, a crystalline film grows on a crystalline substrate or film of another material. This technology is often applied to growing crystalline films of materials of which single crystals cannot be obtained and to fabricating integrated crystalline layers of different materials. Examples include gallium nitride (GaN) on sapphire or aluminium gallium indium phosphide (AlGaN<sub>x</sub>P) on gallium arsenide (GaAs).

**Heterotopotaxy** is a process similar to heteroepitaxy except for the fact that thin film growth is not limited to two dimensional growth. Here the substrate is similar only in structure to the thin film material.

Epitaxy is used in silicon-based manufacturing processes for BJTs and modern CMOS, but it is particularly important for compound semiconductors such as gallium arsenide. Manufacturing issues include control of the amount and uniformity of the deposition's resistivity and thickness, the cleanliness and purity of the surface and the chamber atmosphere, the prevention of the typically much more highly doped substrate wafer's diffusion of dopant to the new layers, imperfections of the growth process, and protecting the surfaces during the manufacture and handling.

## Applications

It has applications in nanotechnology and in semiconductor fabrication. Indeed, epitaxy is the only affordable method of high crystalline quality growth for many semiconductor materials, including technologically important materials as silicon-germanium, gallium nitride, gallium arsenide and indium phosphide.

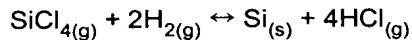
Epitaxy is also used to grow layers of pre-doped silicon on the polished sides of silicon wafers, before they are processed into semiconductor devices. This is typical of power devices, such as those used in pacemakers, vending machine controllers, automobile computers, etc.

## Methods

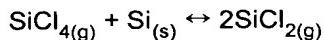
Epitaxial silicon is usually grown using vapor-phase epitaxy (VPE), a modification of chemical vapor deposition. Molecular-beam and liquid-phase epitaxy (MBE and LPE) are also used, mainly for compound semiconductors.

## Vapor-phase

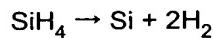
Silicon is most commonly deposited from silicon tetrachloride in hydrogen at approximately 1200 °C:



This reaction is reversible, and the growth rate depends strongly upon the proportion of the two source gases. Growth rates above 2 micrometres per minute produce polycrystalline silicon, and negative growth rates (etching) may occur if too much hydrogen chloride byproduct is present. (In fact, hydrogen chloride may be added intentionally to etch the wafer.) An additional etching reaction competes with the deposition reaction:



Silicon VPE may also use silane, dichlorosilane, and trichlorosilane source gases. For instance, the silane reaction occurs at 650 °C in this way:



This reaction does not inadvertently etch the wafer, and takes place at lower temperatures than deposition from silicon tetrachloride. However, it will form a polycrystalline film unless tightly controlled, and it allows oxidizing species that leak into the reactor to contaminate the epitaxial layer with unwanted compounds such as silicon dioxide.

VPE is sometimes classified by the chemistry of the source gases, such as hydride VPE and metalorganic VPE.

## Liquid-phase

LPE deposits a monocrystalline film from the liquid phase, typically at a rate of 0.1 to 1  $\mu\text{m}/\text{minute}$ .

Liquid phase epitaxy (LPE) is a method to grow semiconductor crystal layers from the melt on solid substrates. This happens at temperatures well below the melting point of the deposited semiconductor. The semiconductor is dissolved in the melt of another material. At conditions that are close to the equilibrium between dissolution and deposition the deposition of the semiconductor crystal on the substrate is slow and uniform. The equilibrium conditions depend very much on the temperature and on the concentration of the dissolved semiconductor in the melt. The growth of the layer from the liquid phase can be controlled by a forced cooling of the melt. Impurity introduction can be strongly reduced. Doping can be achieved by the addition of dopants.

The method is mainly used for the growth of compound semiconductors. Very thin, uniform and high quality layers can be produced. A typical example for the liquid phase epitaxy method is the growth of ternary and quaternary III-V compounds on Galliumarsenid GaAs substrates. As a solvent quite often Gallium is used in this case. Another frequently used substrate is Indiumphosphide InP. However also other substrates like glass or ceramic can be applied for special applications. To facilitate nucleation, and to avoid tension in the grown layer the thermal expansion coefficient of substrate and grown layer should be similar.

## Molecular-beam

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In MBE, a source material is heated to produce an evaporated beam of particles. These particles travel through a very high vacuum ( $10^{-8}$  Pa; practically free space) to the substrate, where they condense. MBE has lower throughput than other forms of epitaxy.

## **Doping**

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An epitaxial layer can be doped during deposition by adding impurities to the source gas, such as arsine, phosphine or diborane. The concentration of impurity in the gas phase determines its concentration in the deposited film. As in CVD, impurities change the deposition rate.

Additionally, the high temperatures at which CVD is performed may allow dopants to diffuse into the growing layer from other layers in the wafer ("autodoping"). Conversely, dopants in the source gas may diffuse into the substrate.